Bedform Dynamics and Mine Burial

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LONG-TERM GOAL

The goal of this work is to develop a predictive understanding of coastal bedforms and their effect on the burial of objects on the seafloor.

OBJECTIVES

The objective of the research is to develop a robust characterization of the growth of the bottom profile envelope (the range from minimum to maximum depth) in the nearshore, both in time and space. The specific objectives are to develop

- a statistical understanding of the time evolution of the bottom profile envelope
- the spatial probability distribution function (PDF) of the bed elevation above envelope minimum i.e., the probability of burial
- a model for prediction of bed profile statistics and mine burial

APPROACH

Large bedforms in the nearshore (with heights of 10 – 50 cm and lengths of 1-10 m) are observed to occur frequently and to be ubiquitous throughout the surf zone (e.g., Clifton et al. 1971, Gallagher et al. 2002, Hay and Wilson 1994, Thornton et al. 1998). However, their dynamics are poorly understood and they are generally neglected in models of sediment transport, morphology change and nearshore dynamics.

The generation and migration of bedforms on shallow-water sandy bottoms in the nearshore provides a mechanism whereby mine-like objects gradually can become buried. As a bedform migrates past a mine, the mine will fall to the low point of the bedform trough before subsequently being buried by the passage of the following bedform crest (Fig 1). Thus, the statistics of mine burial are determined by

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14. ABSTRACT
The goal of this work is to develop a predictive understanding of coastal bedforms and their effect on the burial of objects on the seafloor.

15. SUBJECT TERMS

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the statistics of bed variability, and the mine burial problem is reduced to the problem of understanding the time evolution of the bottom profile envelope. We define the bottom profile as $h(x, \tau)$, and the profile envelope as spanning from $h_{min}(x, \tau)$ to $h_{max}(x, \tau)$. When mines are seeded, $\tau=0$ and the envelope, at a single point on the bed, has zero thickness. As bed features form and migrate the thickness of the envelope grows with time (Fig 2).

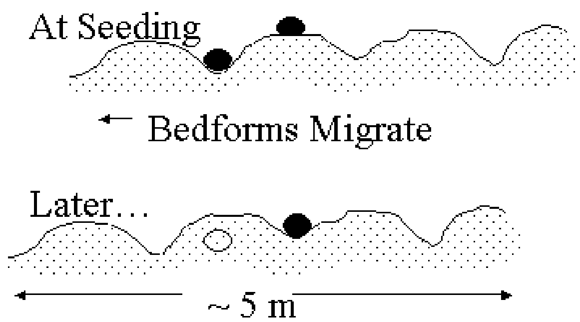

Figure 1: Mine burial by bedform migration.
[Two panels illustrating burial of objects by migrating bedforms.]

Data from the Duck94 Nearshore Field experiment (e.g., Fig 2a solid line) are being used to examine the effect of large ripples (heights 10 – 50 cm) on the temporal variability of the bed profile envelope. Beach profile data from the Field Research Facility are being used to examine the effects of larger scale morphologic changes on bed envelopes. (See Gallagher et al. 1998a, Gallagher et al. 1998b, and www.frf.usace.army.mil for more information on these existing data sets.) It has been hypothesized that the growth, statistics, and spatial distribution of the profile envelope will depend on the overlying wave and current fields. Thus, the existing field data are being used to investigate relationships between the bed envelope and the measured flow parameters. In addition, an exponential taper model is being investigated as a predictive tool for envelope growth (Fig 2b, dotted line).

Drs Gallagher and Holman are working collaboratively on this research and this portion of the proposed work is well under way. Preliminary results from the study of bed profile envelope characterization and prediction are discussed below.

When $D_{max,}$ the envelope thickness, exceeds W, the vertical scale of a mine, the mine can be buried. However, at any subsequent time, the probability of burial depends on the statistics of the instantaneous elevation above envelope minimum, $D = h - h_{min}$. Gallagher et al. (2002) have found that, although bedforms are ubiquitous in shallow water (depth < 4 m), their spatial distribution is patchy and irregular. Spatial patterns become important in determining the fraction of bed area composed of troughs deep enough to re-expose mines i.e., the portion of the bed for which D < W. Conversely, when D > W, mines will be covered. Data from the SandyDuck Nearshore Field Experiment will be used to investigate the spatial distribution of bed profile envelope statistics. Specifically, P, the percentage of the bed area for which full burial is possible, will be calculated. The profile of large bedforms in the nearshore is observed to be negatively skewed (with broad flat crests and deep narrow troughs, Fig 1) so, even if D only just exceeds W, P may be large. In addition, nearshore bedforms are observed, in plan view, to be highly three-dimensional and often lunate in

shape. Thus, mine geometry and 3D morphology will be considered in developing a model for predicting probability and percentage of mine burial. This phase of the research has not been started.

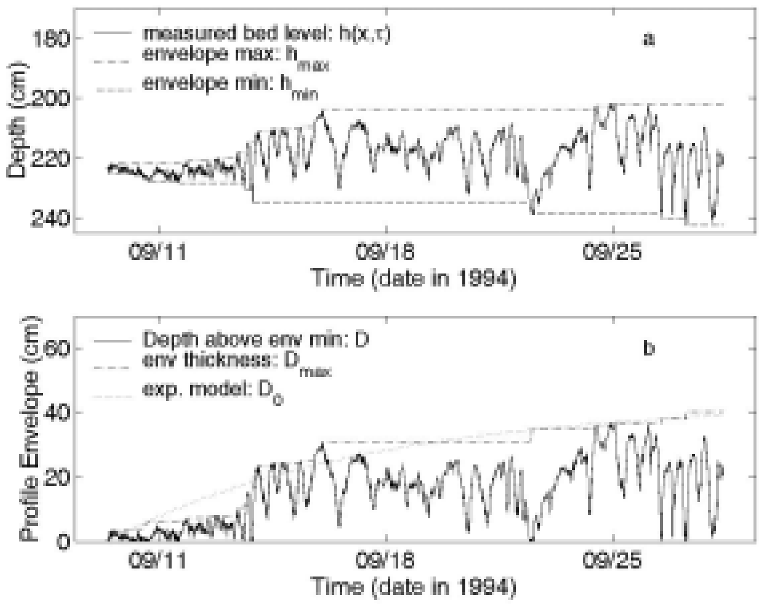

Figure 2: a) Example time series of bed elevation [with 20-30 cm amplitude fluctuations] from a stationary sonar altimeter in 2 m water depth (solid line). The dotted and dashed lines represent the maximum and minimum depths reached during this time period. The profile envelope (dash-dot line in b) is the difference between the dash-dot and dashed lines in a). Also shown in b) is the instantaneous elevation above envelope minimum (solid line) and an exponential taper model fit to the profile envelope (dotted line).

WORK COMPLETED

The bottom profile envelope thickness, D_{max}, has been examined in water depths from 1.5 – 5 m using two months of data from eleven sonar altimeters during the Duck94 Nearshore Field Experiment. Envelope thickness was calculated for 4, 6, 8, and 10 day windows each with 50% overlap, i.e. τ=0 started every 2, 3, 4, or 5 days, respectively and gave n=29, 19, 14, and 11 realizations for the two month data set. A histogram of envelope thickness for the 6-day window is shown in Fig. 3a (black bars). Observed mean and standard deviation of envelope thickness for each window is shown in Fig 3b (asterisks) as a function of time (or window length).

An exponential taper model of the form D_0=b-exp$^{(-ct)}$, where b and c are constants and t is time has been used to represent the data. An example of an exponential taper fit to the time series is seen in Fig 2b (dotted line). Statistics of the parameter b, the asymptote or equivalent of the envelope thickness, from the model being fit to the overlapping windowed time series are shown in Fig 3a (white bars) and their means and standard deviations for each window are shown in Fig 3b (circles). In addition, an exponential taper was fit to mean envelope thickness (asterisks in Fig 3b) and is shown in Fig 3b as a dash-dot line (see discussion below). The statistics of the parameter c, the time dependence of the model, are also being investigated.

The observed bed profile envelope thickness has been compared with various fluid parameters: significant wave height, normalized significant wave height, mean velocity, RMS velocity, total velocity, skewness, and asymmetry. We are continuing to examine the relationship between envelope thickness and the flow field.

RESULTS

The histogram of envelope thickness after 6 days (Fig 3a black bars) shows a peak at about 22 cm. This is in agreement with observations of megaripples, which have amplitudes of 10-50 cm. The second small peak between 60 and 80 cm likely corresponds to larger-scale changes in the morphology, which have not yet been removed from these data. This second peak was not as pronounced for other data windows. The statistics of the model parameter b (Fig 3a white bars) show the same trends as the envelope thickness. However, the model was noted to be unstable when applied to the raw time series i.e., it sometimes had trouble converging. Because non-convergent examples were excluded there are fewer realizations in the histogram of model parameter b (n=160, Fig 3a white bars) than the histogram of measured envelope thickness (n=198, Fig 3a black bars). Owing to this instability the model has been fit to mean envelope thickness (Fig 3b) as well as to the raw time series (e.g. Fig 2b). Both techniques will be investigated for developing a predictive tool.

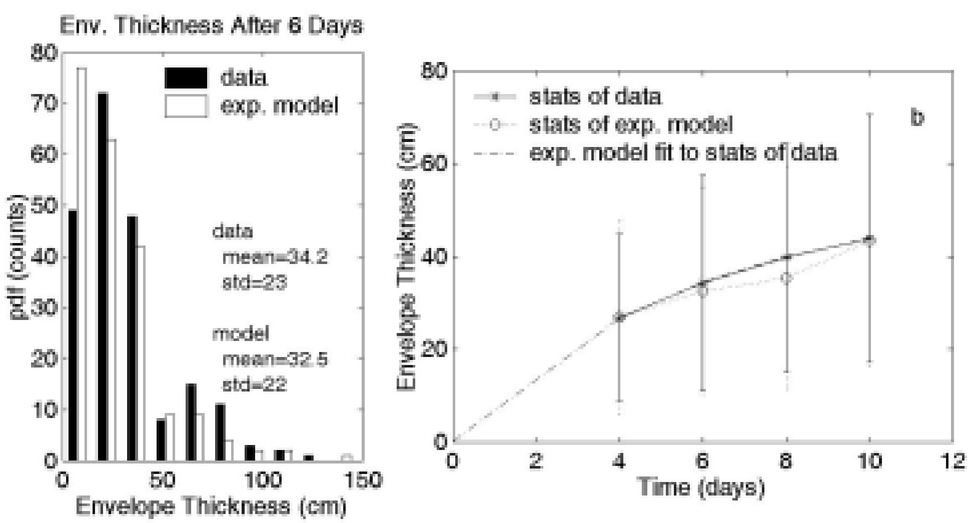

Figure 3. a) Histogram of envelope thickness and model parameter b for 6-day windows. Two months of data were used, with τ=0 starting every 3 days (50% overlap) giving approximately 19 realizations for each of 11 sensors. b) The same data set was sampled using τ=4,6,8, and 10 day windows (all with 50% overlap). Mean envelope thickness and model parameter b (and their standard deviations) are plotted versus window length (asterisks and circles respectively). The mean envelope thickness data were fit with an exponential taper model (dash-dot line). The model is forced through (0,0) since at τ=0 the envelope has zero thickness by definition.

The bed profile envelope grows in time following an exponential taper and suggests an asymptotic level of about 50 cm (Fig 3b). The large standard deviations associated with the means are the result of using all observations for the two month period, including both mild and stormy conditions. A

further step in the analysis will be to separate storm driven changes in the large scale bathymetry from changes in bed elevation owing to migrating megaripples. These two scales of bed profile fluctuation will be examined separately.

Envelope thickness has been compared with significant wave height, which was measured in 8 m water depth and normalized by the water depth at the sensors (Fig 4). The relationship between waves and envelope thickness is surprisingly good and greater predictive ability should be possible with inclusion of additional variables and improvement of the analytical methods. For example, because waves are averaged over the whole time window, conditions that do not contribute to the envelope growth could have a significant effect i.e., one large wave event during low wave conditions could generate bedforms and therefore a large envelope, but the low waves would reduce the average wave height. Appropriate variables and methods are being investigated. Various fluid parameters measured using current meters co-located with the altimeters have been calculated. Interestingly, window-averaged local flow parameters (mean, RMS, total near-bottom water velocity, etc.) are not as well correlated with the envelope thickness (not shown) as the offshore significant wave height.

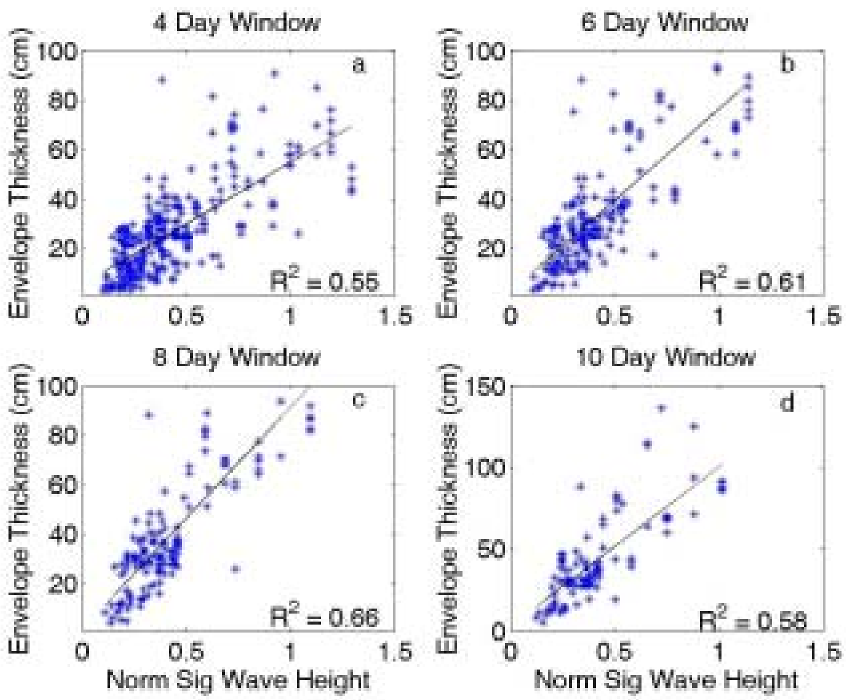

Figure 4. Envelope thickness after a) 4, b) 6, c) 8, and d)10 days versus normalized significant wave height (wave height, measured in 8 m water depth and normalized by the local water depth at the altimeters). [Scatter plots showing a positive correlationt, R^2 = a)0.55, b)0.61, c)0.66, and d)0.58.]

IMPACT/APPLICATION

The threat of mines has an enormous impact on Naval operations. If mining is suspected, methods exist for search and identification of proud mines, but the potential existance of buried mines is of considerable concern. This work will help to describe the process of mine burial by bottom bedform movement, and will quantify the expected time scales, probabilities and depths of burial.

TRANSITIONS

This work has not yet lead to any transitions.

RELATED PROJECTS

This work is part of the Mine Burial Program, a coordinated effort to study all processes of mine burial including impact and scour burial.

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